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RECENT EXPERIENCE IN THE FABRICATION AND BRAZING OF CERAMIC BEAM TUBES FOR KICKER MAGNETS AT FNAL *

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Abstract

Ceramic beam tubes are utilized in numerous kicker magnets in different accelerator rings at Fermi National Accelerator Laboratory. Kovar flanges are brazed onto each beam tube end, since kovar and high alumina ceramic have similar expansion curves. The tube, kovar flange, end piece, and braze foil (titanium/incusil) alloy brazing material are stacked in the furnace and then brazed in the furnace at 1000 ^{0}C. The ceramic specified is 99.8% Alumina, Al_2O_3, a strong recrystallized high-alumina fabricated by slip casting. Recent experience at Fermilab with the fabrication and brazing of these tubes has brought to light numerous problems including tube breakage and cracking and also the difficulty of brazing the tube to produce a leak-tight joint. These problems may be due to the ceramic quality, voids in the ceramic, thinness of the wall, and micro-cracks in the ends which make it difficult to braze because it cannot fill tiny surface cracks which are caused by grain pullout during the cutting process. Solutions which are being investigated include lapping the ends of the tubes before brazing to eliminate the micro-cracks and also metallization of the tubes.

BACKGROUND

Ceramic beam tubes have been used for kicker magnets at Fermilab since its inception. There are two reasons for using ceramic chambers in kickers: 1) to avoid shielding of a fast changing external magnetic field by metallic chamber walls and 2) to reduce heating due to eddy currents. The inner surfaces of the ceramic chambers are coated with a conductive coating to reduce the beam coupling impedance and provide passage for beam image current. They have been used for fast kickers, abort kickers, and also bucket and pinger magnets. They must meet requirements including length, straightness in order to fit into the magnet, and have sufficient strength to withstand atmospheric and mechanical forces encountered during assembly and operation.

The ceramic beam tubes have been found to be very low yield and the largest technical risk for the kickers in all the recent projects at Fermilab.

DESIGN

An elliptical shaped tube was decided upon in order to give the proper beam aperture and also adequate strength in order to withstand vacuum with thin walls, approximately 4.8 mm (3/16 inch).

Ceramic tubes produced for other Fermilab projects have included other shapes, including rectangular. Depending on the beam aperture and beam line requirements, the inner and out diameter of the tube sizes are optimized.

An ANSYS model of a 2.1 m long tube with a 33 mm vertical and an 81 mm horizontal aperture was created and with a vacuum load on the tube (Figure 1). It was found that the stress level was 13.14 MPa (1907 psi). This ceramic has a typical flexural strength of 331 MPa (48,000 psi) and a compressive strength of over 2068 MPa (300,000 psi).

FABRICATION OF TUBES

In order to make a tube that is 2.0 m (80 inches) long, a mandrel of 3.1 m (122 inches) has to be used in order to compensate for the fact that the ceramic shrinks about 22% and there is about 203 mm (8 inches) of waste tube on each end due to manufacturing techniques. Ceramic tubes are fabricated using a slip cast method using a straight tapered mandrel, with a taper of about 0.127 mm (.005 inch) per 304 mm (1 foot).

Slip casting involves a plaster mold and a slip which consists of a suspension of ceramic particles in a liquid that is usually water. The arbor is removed from inside the tube and the tube is removed from the mold. In this condition it is in a green state and is slightly pliable. The tube is then hung inside a furnace, where gas jets bake it. The force of the gas jets can cause a tube to warp and twist.

The mandrel is made of T-6061 aluminum by Vesuvius. It is tapered approximately .013 degrees from straight all around in 3.3 m (130 inches) length for removal from the mold.

Isostatically pressed tubes have been manufactured for other Laboratories, including CERN [1]. In isopressing, the press mix is placed in an elastomer bag and compacted with hydraulic pressure on the exterior of the bag. One of the principal advantages of isopressing is that the pressing is uniformly compacted, which results in more uniform sintering [2].

McDanel Advanced Ceramic Technologies has fabricated the tubes (Figure 2) and will provide Fermilab with the material certifications verifying that the material is 99.8% alumina. The dimensions of the tubes thus far have been within the dimensional bounding boxes required.

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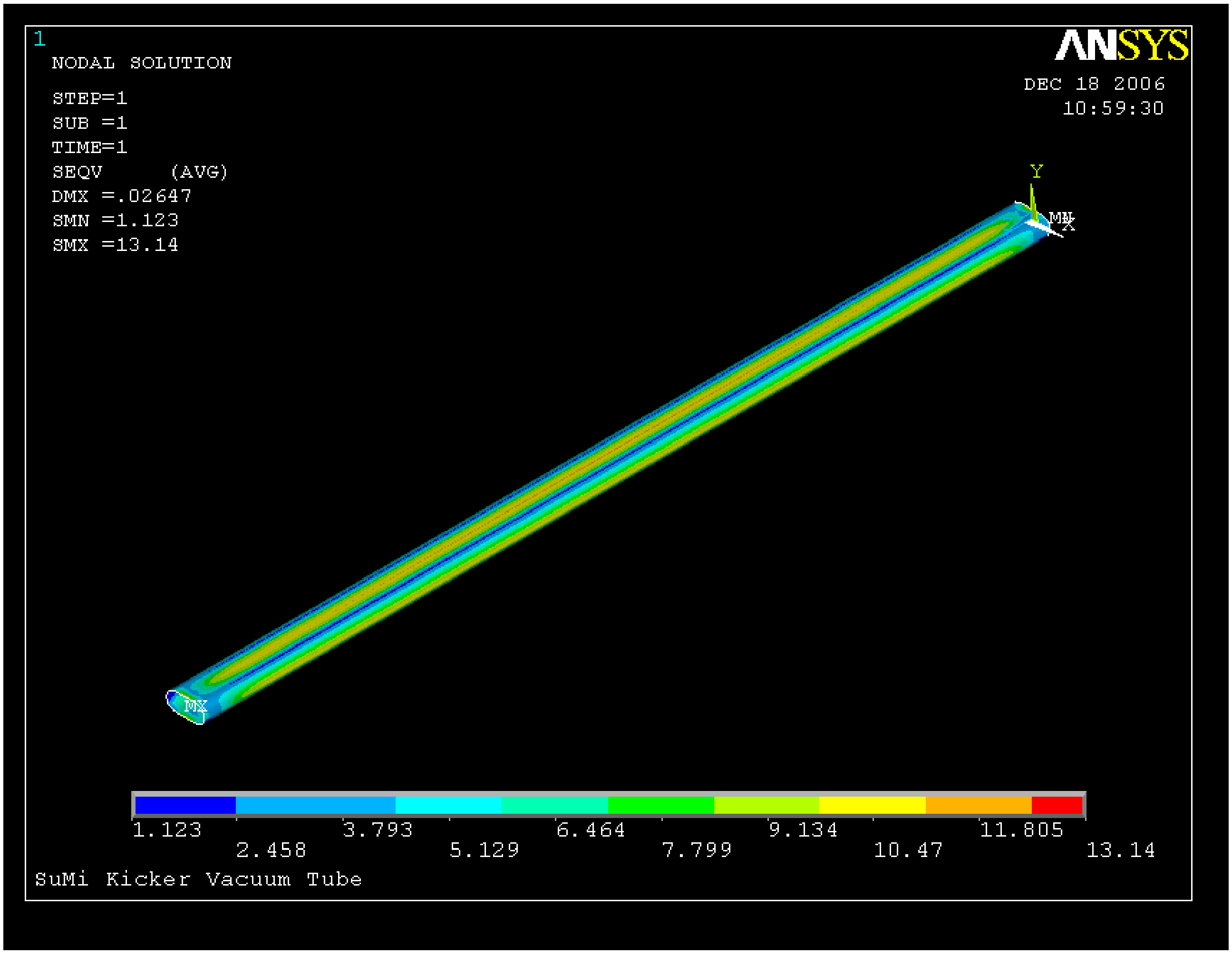

Figure 1: ANSYS model of ceramic beam tube.

The ceramic tubes fabricated in the past by Coorstek (Coors Porcelain Division) had a wall thickness that is almost 50% larger than that of McDanel's. This may be a factor in why there have been difficulties in brazing. It had larger grains and a more uniform grain structure. Additionally, it was denser since it was subjected to a higher firing temperature. Finally, it is more polished when the ends are lapped with less grain pullout due to the uniformity and higher density.

Figure 2: Recently fabricated tubes from McDanel.

CERAMIC TO KOVAR VACUUM TRANSITIONS

Kovar is used to braze to the ceramic because the coefficients of expansion of the ceramic and this metal are closely matched. Nickel and nickel alloys can also be used because they are very ductile and are able to absorb the stresses. Kovar is an alloy of 29% Ni, 17% Co, 0.30% Mn, with iron making up the balance.

The kovar disc on the tube is dished in order to take the radial expansion and contraction forces of the flange on the tube during the brazing process. The flange is made with an ID about 6.35 mm too small so that there will be about 3.2 mm lip all around the inner diameter of the tube. This provides some tolerance if the tube moves during the brazing process and also more surface area for the braze material.

The tube, flange, end piece and a braze foil made of titanium and incusel are stacked in the furnace with about six pounds of weights to hold them together when they are in the furnace. The tube is brazed to about 850 C (Figure 3).

Before brazing, lapping has been used on the tube ends to reduce the number of near-surface micro-cracks. This surface damage can increase the probability that residual stresses will produce catastrophic cracks during the cooling of ceramic-to-metal joints, and can reduce the load-carrying capability of both ceramic and ceramic-to-metal joints. Lapping is a process that uses a fine, loose adhesive in a fluid suspension to produce very fine surface texture and a high degree of flatness [3].

CeramTec has worked on brazing two shorter tubes with the same cross-sections as all the other tubes and neither tube is leak tight. They have been able to remove the three non-leak tight brazed flanges by using a nitric acid solution. This is a new method of recovering beam-tubes without re-cutting. They re-lap the tubes and used a thin pencil blast using a "talcum-powder" like sand-blast to remove the residue.

Other Labs such as Los Alamos have fabricated tubes with the tube made in two pieces, a top and bottom. This allows for metallic stripes to be put inside and also the pieces to be planar and parallel over the entire 10-meter length [4]. The ceramic tubes are then brazed with a glass frit mixture which is basically crushed glass. Fermilab is investigating a similar idea using brazing with glass frit.

Flange brazing is the most challenging aspect of fabricating the kicker magnets. Recently produced rectangular tubes for the Booster Ring have had less than a 20% vacuum-leak tightness rate.

Argonne National Laboratory has had similar problems brazing kovar to ceramic. They eventually had to epoxy the flanges to the positron accumulator ring and injector synchrotron rings kicker tubes because of this [5].

Active brazing has been used because no vendors have been found which can metallize long tubes. However, Kyocera in Japan states they can metallize long tubes, up to 1.5 m. Ceramic is metallized with 80% molybdenum and 20% manganese powder of 1 to 5 micron particles in a binder which is burned off during firing at 1500 C in a wet hydrogen furnace. The metal powder sinters, penetrates the ceramic surface, and bonds with the ceramic, forming a coating 0.025 to 0.038 mm thick. A second coating is needed to get the solder to wet the metallized area during brazing. The metallized area is then nickel plated it a thickness of 0.003 mm, then re-fired in a reducing atmosphere of 1000 C. The nickel coating enhances wetting and facilitates leak-tight joints.

COATING OF THE CERAMIC CHAMBERS

The ceramic tubes require an internal, surface charge bleed coating. The requirements are that the coating must be conductive to carry the charge buildup, yet sufficiently thin so as to have negligible effect on the magnet fields. In addition, the coating must have a very low vapor pressure, so as not to affect the system vacuum. A graphite coating has been used.

It is critical that the coating completely cover the inside of the tube but is less important for the coating to be even. The resistance of the coating needs to be in the k-Ohm range. In instances with low vacuum requirements, no bake-out of the coating is necessary. For more stringent vacuum requirements, the coating is baked to reduce out-gassing.

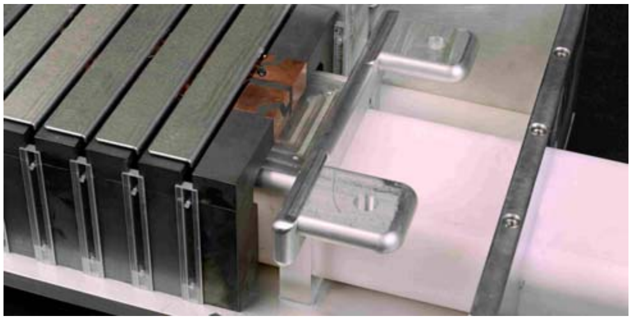

Figure 3: Recycler Ring kicker magnet.

SUMMARY

Purchase requisitions for three tubes each for Kyocera and Omley are being written. Fermilab has not had experience with Kyocera metallizing long tubes. Additionally, a developmental process requisition will be pursued with Thermofusion. This company is developing a propertiary idea which they feel will greatly increase the percentage of leak-tight tubes. The magnet design will continue and the plan is that six gap clearing kickers will be ready for installation next year (Figure 3).

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